Net Charge and Isospin Fluctuations in the World of Elementary Particles

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Charge and isospin event-by-event fluctuations in high-energy pp-collisions are predicted within the Unitary Eikonal Model (**UEM**), in particular the fluctuation patterns of the ratios of charged-to-charged and neutral-to-charged pions. These fluctuations are found to be sensitive to the presence of unstable resonances, such as ρ and ω mesons.We predict that the charge-fluctuation observable D_{UEM} should be restricted to the interval $8/3 \leq D_{UEM} \leq 4$ depending on the ρ/π production ratio.This result is shown to be compatible with the formation of a hadron gas at RHIC and SPS energies.

1 Introduction

A large number of particles produced in a single central ultrarelativistic heavy-ion collision at RHIC (Relativistic Heavy Ion Collider)and LHC (Large Hadron Collider) gives us a remarkable opportunity to study fluctuations of specific hadronic observables on the event-by-event basis [Blume,2002]. High energy hadron-nucleus, nucleus-nucleus and heavy-ion collisions may be treated as a linear superposition of pp-collisions [Bialas *et al.*,1976].

2 Charge Fluctuations

The event-by-event fluctuations of the ratio of positively and negatively charged pions can be a distinct signal of Quark Gluon Plasma (QGP) formation [Jeon & Koch,2000] (in the QGP phase the unit of charge is 1/3 while in the hadronic phase the unit of charge is 1).

The fluctuations of the total charge multiplicity $N_{ch} = N_+ + N_-$, and the net charge $Q = N_+ - N_-$, are defined [Heiselberg & Jackson, 2001] as

$$\frac{\langle (N_+ \pm N_-)^2 \rangle - \langle N_+ \pm N_- \rangle^2}{\langle N_+ + N_- \rangle} = \frac{\langle N_+ \rangle}{\langle N_{ch} \rangle}\omega_{N_+} + \frac{\langle N_- \rangle}{\langle N_{ch} \rangle}\omega_{N_-} \pm C\,, \tag{1}$$

where the correlation is given by

$$C = \frac{\langle N_+ N_- \rangle - \langle N_+ \rangle \langle N_- \rangle}{\langle N_{ch} \rangle / 2}\,. \tag{2}$$

In experiments, $\omega_{N_+} \approx \omega_{N_-}$, so that the fluctuation in total charge simplifies to

$$\omega_{N_{ch}} \equiv \frac{\langle N_{ch}^2 \rangle - \langle N_{ch} \rangle^2}{\langle N_{ch} \rangle} = \omega_{N_+} + C\,, \tag{3}$$

and that for the net charge becomes

$$\omega_Q \equiv \frac{\langle Q^2 \rangle - \langle Q \rangle^2}{\langle N_{ch} \rangle} = \omega_{N_+} - C\,. \tag{4}$$

The ratio of particle multiplicities is considered to avoid the volume fluctuations ($\pi^+/\pi^-, K/\pi$). A suitable observables define by these ratios are $F = Q/N_{ch}$ and $R = N_+/N_-$.

If $\langle N_{\mathrm{ch}}\rangle \gg \langle Q\rangle$ then

$$\langle \delta R^2\rangle = \langle R^2\rangle - \langle R\rangle^2 \approx 4\langle \delta F^2\rangle \tag{5}$$

and

$$\langle \delta F^2\rangle = \frac{\langle Q\rangle^2}{\langle N_{\mathrm{ch}}\rangle^2}\langle\left(\frac{\delta Q}{\langle Q\rangle} - \frac{\delta N_{\mathrm{ch}}}{\langle N\rangle_{\mathrm{ch}}}\right)^2\rangle \tag{6}$$

The fluctuations of the ratio $R = N_+/N_-$ are connected to the fluctuations in the net charge through the observable

$$D \equiv \langle N_{\mathrm{ch}}\rangle\langle \delta R^2\rangle = 4\langle N_{\mathrm{ch}}\rangle\langle \delta F^2\rangle = 4\frac{\langle \delta Q^2\rangle}{\langle N_{\mathrm{ch}}\rangle} \tag{7}$$

which provides a measure of the charge fluctuations per unit entropy.

Because of the effects of the finite net charge and the finite acceptance window in the experiments the observable D should be corrected (UrQMD - Ultra-relativistic Quantum Molecular Dynamics model [Bleicher *et al.*, 2000])

$$D \Longrightarrow \tilde{D} = \frac{\langle N_{\mathrm{ch}}\rangle_{\Delta y}\langle \delta R^2\rangle_{\Delta y}}{C_\mu\, C_y} \tag{8}$$

and

$$C_\mu = \tilde{R}^2_{\Delta y} = \frac{\langle N_+\rangle^2_{\Delta y}}{\langle N_-\rangle^2_{\Delta y}} \tag{9}$$

$$C_y = 1 - P = 1 - \frac{\langle N_{\mathrm{ch}}\rangle_{\Delta y}}{\langle N_{\mathrm{ch}}\rangle_{\mathrm{total}}} \quad . \tag{10}$$

We have calculated observable D within the Unitary Eikonal Model (UEM) [Martinis *et al.* 1994], [Martinis *et al.* 1995] and compared it with the predictions of the termal model, UrQMD model for hadron gas, and Quark-Gluon gas model.

3 Unitary Eikonal Model

The UEM is based on the fact that at high energies most of the pions are produced in the nearly baryon-free central region of the phase space. The energy available for their production is

$$E_{had} = \frac{1}{2}\sqrt{s} - E_{leading} \tag{11}$$

which at fixed total c.m. energy $\sqrt{s}$ varies from event-to-event.

The coherent production of pions or clusters of pions in the impact parameter space of leading particles is described by the factorized form of the scattering amplitude. It is characterized by the product of classical source functions describing the production of a cluster of pions with a definite isospin index. The cluster decays into pions outside the region of strong interactions (i.e. the final-state interaction between pions is neglected.

Studies of nucleus-nucleus and heavy-ion collisions at the partonic level suggest that the central region is mainly dominated by gluon jets. Since gluon's isospin is zero, it is very likely that total isospin of the produced pion cloud in the central region is also zero. We assume global conservation of isospin.

We consider the cloud of N pions produced in pp-collisions which consists of N_π directly produced pions and $2N_\rho$ pions produced via ρ-type clusters such that $N = N_\pi + 2N_\rho$. The probability distribution of producing N_+, N_- and N_0 pions in the impact parameter space, such that $N = N_+ + N_- + N_0$, is

$$\begin{aligned} &P_{II_3}(N_+N_-N_0 \mid N)C_{II_3}(N) = \\ &\qquad \sum_{I'I'_3} \omega_{I',I'_3} \int d^2b dq_1 dq_2 \ldots dq_N \mid \langle I'I'_3, N_+N_-N_0 \mid \hat{S}(s,\vec{b}) \mid II_3\rangle \mid^2) \end{aligned} \tag{12}$$

where

$$\begin{aligned} N &= N_+ + N_- + N_0 \\ N_+ &= n_{\pi^+} + n_{\rho^+} + n_{\rho^0} \\ N_- &= n_{\pi^-} + n_{\rho^-} + n_{\rho^0} \\ N_0 &= n_{\pi^0} + n_{\rho^+} + n_{\rho^-} \end{aligned} \tag{13}$$

4 Results

We predict that the charge-fluctuation observable D_{UEM} should be restricted to the interval

$$8/3 \leq D_{UEM} \leq 4 \tag{14}$$

depending on the ρ/π production ratio. The upper bound $D_{UEM} = 4$ is satisfied if $\overline{n}_\rho = 0$. In that case the pion production is restricted only by the global conservation of isospin. However, if $\overline{n}_\pi = 0$ the lower limit is $D_{UEM} = 8/3$. The predictions of the UrQMD model are

$$\tilde{D} = \frac{\langle N_{\mathrm{ch}} \rangle_{\Delta y} \langle \delta R^2 \rangle_{\Delta y}}{C_\mu C_y} = \begin{cases} 1 & \text{quark gluon gas} \\ 2.8 & \text{resonance gas} \\ 4 & \text{uncorrelated pion gas} \end{cases} \tag{15}$$

what is in a good agreement with the results of our model (Eq.(14)).

5 Conclusion

Our results are shown to be compatible with the formation of a hadron gas at RHIC and SPS energies [Adcox, 2002],[Blume, 2002],[Reid, 2002] and differ noticeably from that expected for QGP .We can conclude that there is no indication for Quark-Gluon-Plasma yet.

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